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EFFECT OF V SHAPE NOTCH LOCATION ON FATIGUE LIFE IN STEELBEAM MADE OF CARBON STEEL ALLOYS WITH DIFFERENT CONTENT OF CARBON

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ABSTRACT

In this investigation effect of V shape notch location on fatigue life in steel beam made of carbon steel alloys with different carbon content (low, medium and high) has been studied. Fatigue life of notched specimens where there is a change in V notch shape location is calculated by applying a fully reversed cyclic load.The fatigue experiments were carried out at room temperature, with thefrequency of 50Hz and mean stress equal to zero (R= -1), on a cantilever rotating-bending fatigue testing machine. The stress ratio was kept constant throughout the experiment. Simulation by FEA have been used to estimate fatigue data based on fatigue life data obtained from the experiments for smooth specimens (reference),The results show that the notch effect become not important at the position no. 5 (central of gauge length) regardless of type of material used and there isacceptable error between experimental and numerical works.

KEYWORDS: Fatigue Strength Notch, Stress Life Approach, Fatigue Life, Stress Concentration Factor, FEA

INTRODUCTION

Metal fatigue is a process which causes premature failure or damage of acomponent subjected to repeated loading. It is a complicated metallurgicalprocess which is difficult to accurately describe and model on the microscopiclevel. Despite these complexities, fatigue damage assessment for design ofcomponents and structures must be made [1]. Metal fatigue is caused by repeatedly applying a nominal load to and from ametal part.

This is known as the cyclic load. After this cyclic load is appliedover a period of time of load-unloaded cycles will cause the metal part tobreak [2]. Fatigue failure is caused by many factors such as material type, notch geometry, surface quality, environment effect and etc. Notches are notorious for influencing the stress distribution in producing high localized stresses.

This factor, known simply as the theoretical stress concentration factor, *Kt* is one of importance as its localized stress raiser is known to increase the applied force at the concentrated region, sometimes to a height above the crack opening threshold stress, thus expediting fatigue crack initiation [3].Generally, fatigue crack growth behavior of notched componentsdepends on the state of stress at the notch front, geometry ofthe component, shape and size of the notch, and loading conditions[4]. Discontinuities in metallic components give rise to stress concentrations at whichfatigue cracks initiate.

The presence of a Haw at a geometric stress concentration, such as a notch root, will further increase the local stresses and strains and reducethe component’s fatigue strength. [5].Reference [6] explained stress raisers and its effect on Fatigue sensitivity.BuketOkutan [7] studied the effect of notch (hole’s) position andbolt preload on bolted connectors' fatigue life.R[8] developed experimental and theoretical life on notched specimens under bending.

Fatigue life of notched specimens with various notch geometries and dimensions was investigated by experiment and by using Manson-Caffin analytical method. Taylor and et al. [9] have studied effect of surface roughness on fatigue life, they compared the fatigue limit of the notched specimen made of AISI 4140 steel, using four types of machined surfaces produced by polishing, grinding, milling and shaping.

The objectives of this study is to estimate fatigue data of V shape notch of various carbon steel alloys with different distance from the maximum region by experiments using rotating bending fatigue at fully reversed loading (R = -1) and to compare the fatigue analysis by using FEA to identify the effective distance of gauge length of specimens.

EXPERIMENTAL SETUP

The experimental work included assessment of fatigue life specifications by using stress life approach for different Carbon steel alloys supplied from the local market for smooth and notched specimens and the effect of V shape notch locationon the fatigue life. The experimental procedure includes selection of materials used, different mechanical tests, fatigue test and Microscopic inspection.

Material Selection

In this work, three Carbon steel alloys AISI 1020, AISI 1035 & AISI 1078 treated commercially, were used in this investigation, those types of steel alloys have a wide application in industry, the chemical composition test of each alloy was done by use the Spectrometer analyzer the results were within the specification limits[10], as shown in table 1.

Mechanical Tests

The tensile test is a standard test which was conducted using the microcomputer controlled electronic universal testing machine at room temperature. Average value of four readings for the test of each material has been taken to satisfy an additional accuracy. Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration, though there are two tests have been done in this investigation Brinell's and Vickers's Hardness test.

The average value of four readings was recorded the results of mechanical properties of the selected materials are given in table 2. For more details about the Tensile and Hardness tests procedure see [11].

Table 1: Chemical Composition of Carbon Steel Alloys (Wt %)

Elem.	Measured			Standard		
	LCS	MCS	HCS	LCS	MCS	HCS
C	0.208	0.369	0.773	0.17-0.23	0.32-0.28	072-0.85
Si	0.270	0.303	0.236	-	0.270	-
Mn	0.603	0.738	0.327	0.3-0.6	0.7-1.0	0.3-0.6
P	0.012	0.009	0.006	≤ 0.04	≤ 0.04	≤ 0.04
S	0.021	0.023	0.012	≤ 0.05	≤ 0.05	≤ 0.05
Cr	0.080	0.94	016	-	-	-
Mo	0.002	0.008	0.002	-	-	-
Ni	0.082	0.245	0.069	-	-	-
Al	0.018	0.02	0.04	-	-	-
Cu	0.161	0.209	0.062	-	-	-
V	0.000	0.000	0.000	-	-	-
Fe	Bal.	Bal.	Bal.	99.08-99.53	98.53-99.98	98.5-99.98

Table 2: Tensile Test Results

Material	Property	Value
Low carbon Steel (AISI 1020)	σu (MPa)	470
	σy (MPa	350
	Elongation [%]	26
	Modula's of Elasticity (Gpa)	202
	Brinell Hardness (HB)	135
	Vickers Hardness (HV)	142
Medium carbon Steel (AISI 1035)	σu (MPa)	575
	σy (MPa	480
	Elongation [%]	18
	E (Gpa)	206
	Brinell Hardness (HB)	172
	Vickers Hardness(HV)	180
High Carbon Steel (AISI 1078)	σu (MPa)	675
	σy (MPa	510
	Elongation [%]	15
	E Gpa)	200
	Brinell Hardness (HB	200
	Vickers Hardness(HV)	220

Fatigue Test

In the revolving fatigue testing machine, a rotating sample which is clamped on one side is loaded with a concentrated force. The load is applied at one end of the sample and with the help of a motor, rotation about its own axis is achieved. Due to this rotation, a load reversal condition is achieved at two opposite sides on the circumference of the specimen. A triangular bending moment is developed in the specimen.

Following a certain number of load cycles, the sample will rupture as a result of material fatigue A cantilever bending fixture was designed to test the steel specimens based on the critical (i.e. failure) location. Cantilever bending was used in order to minimize the magnitude of the applied loads necessary to achieve the desired nominal stresses. Stresses at which the material fails below the load cycle limit are termed fatigue limit. S-N curves are plotted by using software of Fatigue instrument presented in PC which is connected directly to fatigue machine.

The surface quality of the fatigue test specimens is very important, because the fatigue cracks tend to initiate from the specimen surface where the loading stress is the highest. The increase of surface roughness enhances the stress concentration at the bottom of scratch marks, resulting, thus, in a decrease in fatigue life.

In surface-related fatigue fracture, cracks tend to initiate at the bottom of scratch marks [12], i.e., surface roughness acts as a small notch. The surface roughness was measuredby using a portable Surface roughness tester, the average and total surface roughness, R_a and R_t are calculated and summarized in table 3; for more details about the fatigue test specimens geometry& machine, see [13].

Table 3: Surface Roughness Results

Material	Ra [µm]	Rt [µm] Max.
Low carbon steel	0.5	1.75
Medium carbon steel	0.5	1.8
High carbon steel	0.45	1.7

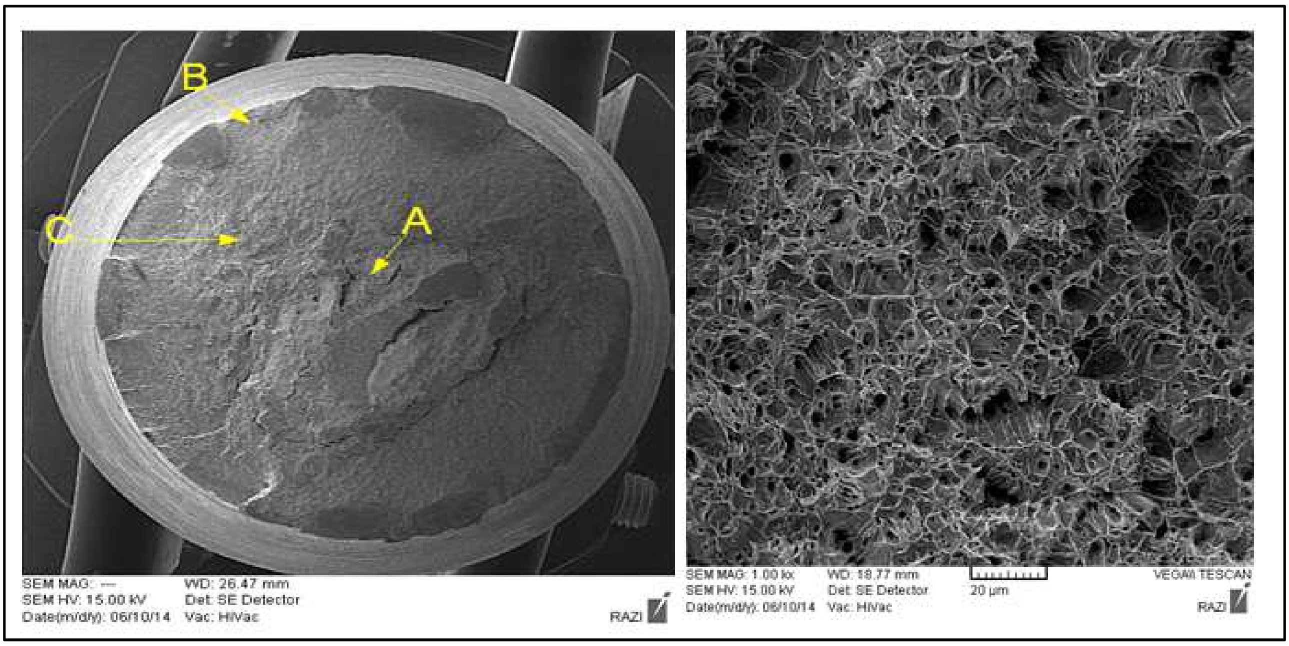

Figure 1: SEM Micrograph of Fractured Surface of investigated Medium Carbon Steel

CORRELATION OF STRESS-LIFE DATA

For a set of amplitude-mean-life data, it is useful to employ Least Square Method where in many branches of applied mathematics and engineering sciences we come across experiments and problems, which involve two variables. For example, it is known that the Stress amplitude σ_a of a steel specimens in S-N curve varies with the cycles of failure N according to the Basquin's formula $\sigma_a = aN_f^b$ Here a and b are the constants to be determined. For this purpose we take several sets of readings of stress amplitude and the corresponding Cycles. The problem is to find the best values for a and b using the observed values of σ_a and N, thus, the general problem is to find a suitable relation or law that may exist between the variables x and y from a given set of observed values,(xi, yi), i = 1, 2,..........,n. Such a relation connecting x and y is known as empirical law. For above example, $x = \sigma_a$ and y = N. The process of finding the equation of the curve of best fit, which may be most suitable for predicting the unknown values, is known as curve fitting. Therefore, curve fitting means an exact relationship between two variables by algebraic equations. There are following methods for fitting a curve. The graphical method has the drawback in that the straight line drawn may not be unique but principle of least squares provides a unique set of values to the constants and hence suggests a curve of best fit to the given data. The method of least square is probably the most systematic procedure to fit a unique curve through the given data points[14].

NUMERICAL INVESTIGATION

Numerical analyses on the geometry of both smooth and notched specimens were done to determine its stress distribution at varying magnitudes. A 3D model of the fatigue notched specimen with angle orientation 45 degree and notch depth 0.5 & 2 mm using tetrahedral shaped elements was generated using ANSYS Workbench software 11. BY use FEA It is able to analyze the different components from varied aspects such as fatigue life data. 20 Nodequadratic hexahedral solid186 elements were considered. An elastic-isotropic material model was used to represent the selected materials stress-strain behavior. The mechanical properties and stress life data obtained by experiments and specimens with different content of carbon and geometry are modeled, the element meshes were generated, boundary condition

corresponding to exact notch position were defined and stress analysis with constant amplitude fully reversed loading was applied to the structure. The size of the elements was refined several times in order to obtain a converged solution (element independent result). After simulation fatigue analysis, designvariables were defined and the influence of the V notch position on fatigue life was estimated. Analysis of different stress, life damage, biaxility and safety factor for selected materials have been done, results are generated for fatigue loading fatigue at different stress amplitude and different S-N curves have been done.

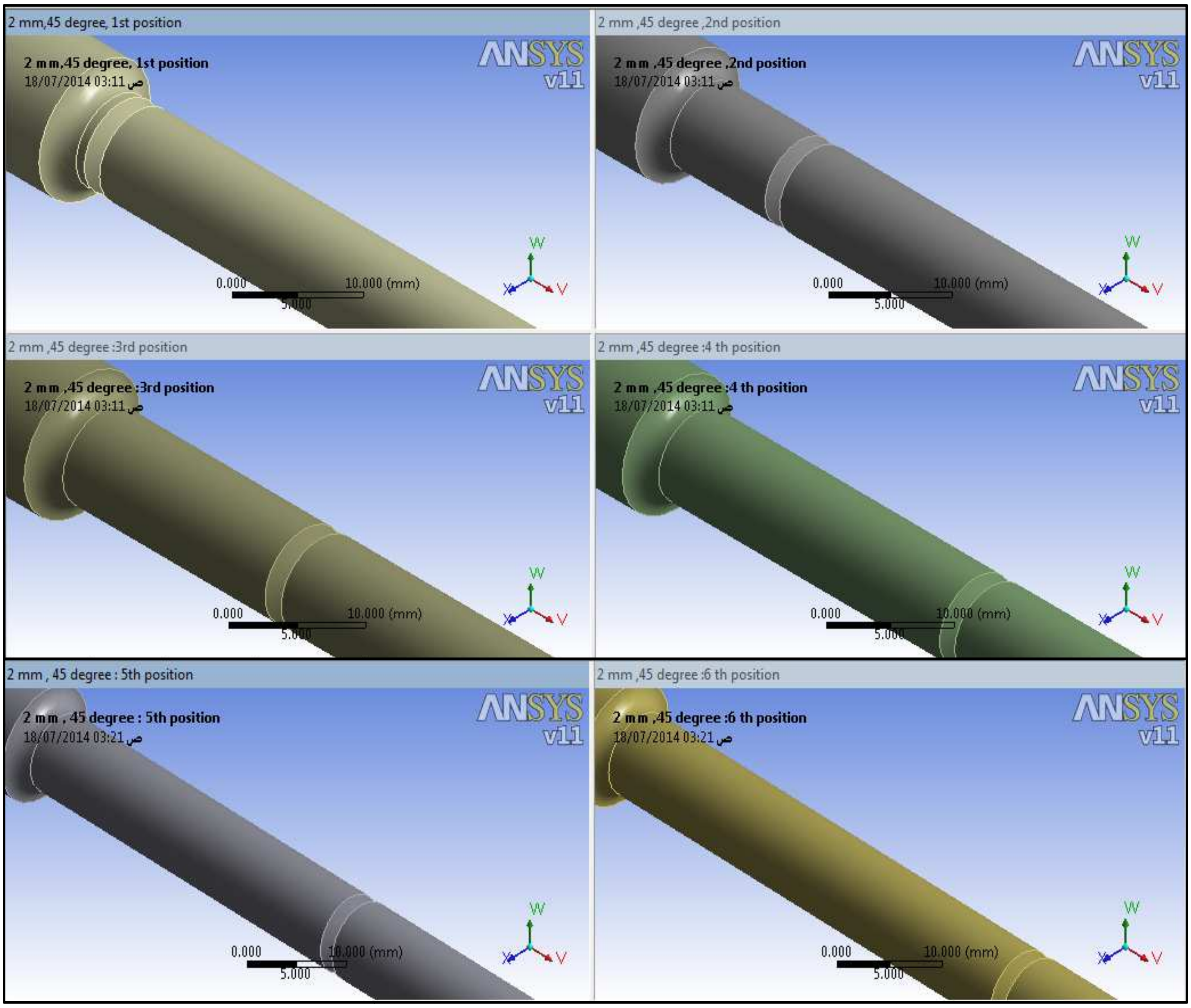

Figure 2: Modelsfor Notched Specimen (45 Degree, 2 mm) with Different Positions of V Shape

RESULTS

In his work, bending fatigue life of notched specimens with V notch geometry of various angle orientation and notch depth was investigated by experiment and FEA methodon the basis of stress amplitude developed obtained from experiments. Fatigue simulation by finite element for notched specimen under stress controlled cyclic loading had been done. The mathematical form of fatigue life equation of the specimens, were obtained by experiment and by use FEA.Microstructure investigations under light (LM) andscanning electron (SEM) microscopes were alsoperformed. Standard metallographic specimens weremade and the microstructures were observed at differentmagnifications in the rolling and perpendicular directions. Figure 1 show SEM micrographs of typical fractured surfaces of the medium carbon steel specimens after fatigue testing with theSEM&EDX device.The fractured surfaces are striated due to the fatiguing

ofthe material. The cracks also spread perpendicularly tothe notch tip and are initiated on the larger hard particles. Stress concentration factor wasobtained by using finite element method for different angle orientation and notch depths at the central position as shown in Figure 3. Fatigue concentration factor for each alloy was found also under effect of revered bending and stress concentration factoras shown in Figure 4, based on different fillet radii by using below equation :

$$K_f = 1 + (K_t - 1)\, q$$

$$q = \frac{1}{1 + \frac{a}{r}}$$

Where q is the notch sensitivity and it can be defined from the Kunn-Hardarth formula in terms of Neuber's constant (a) and the notch radius (r).

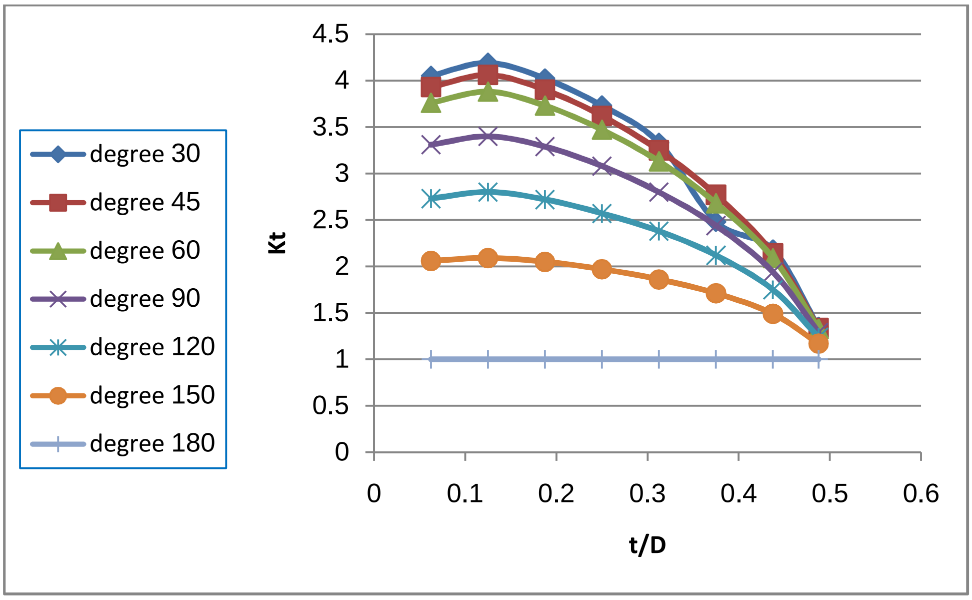

Figure 3: Stress Concentration Factor for Different Angle Orientation (Low Carbon Steel)

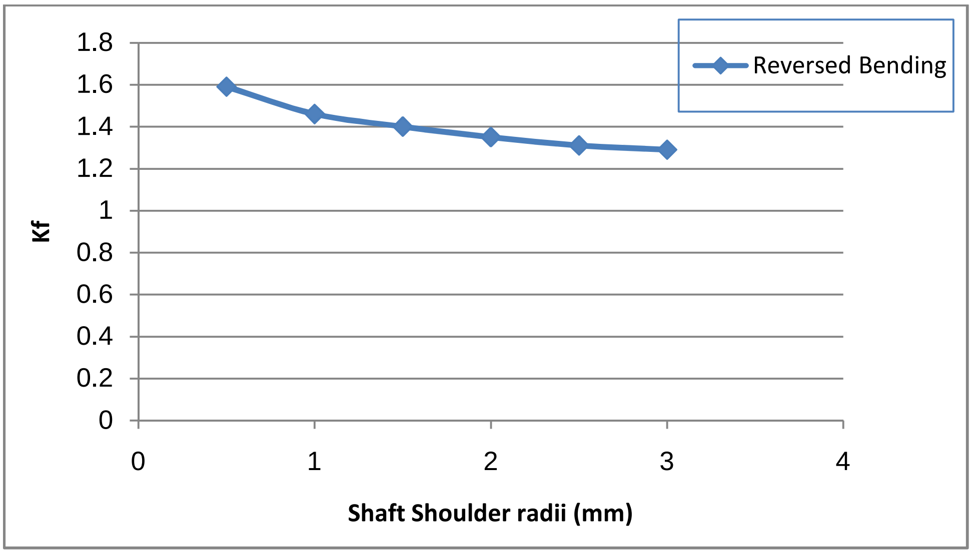

Figure 4: Fatigue Concentration Factor for Different Fillet Radii (Low Carbon Steel)

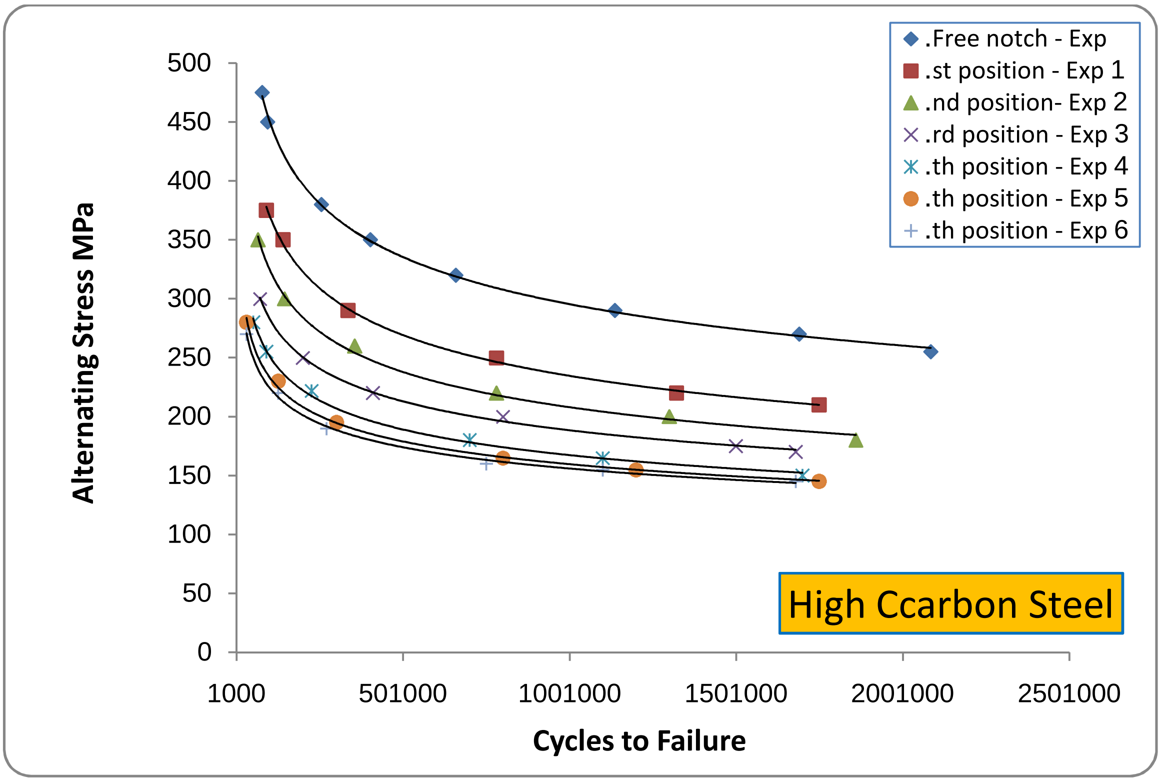

Figure 5: Experimental S-N Curves for V Notched Specimens Made of High Carbon Steel with Different Positions

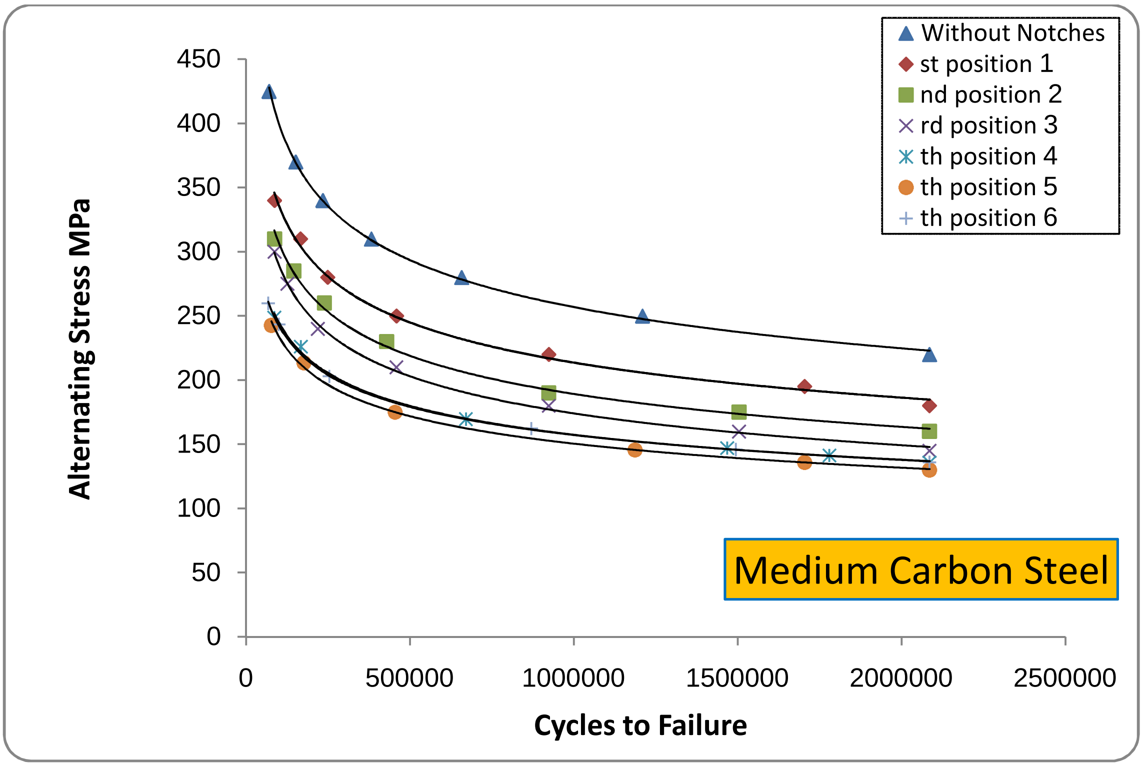

Figure 6: Numerical S-N Curves for V Notched Specimens Made of Medium Carbon Steel with Different Positions

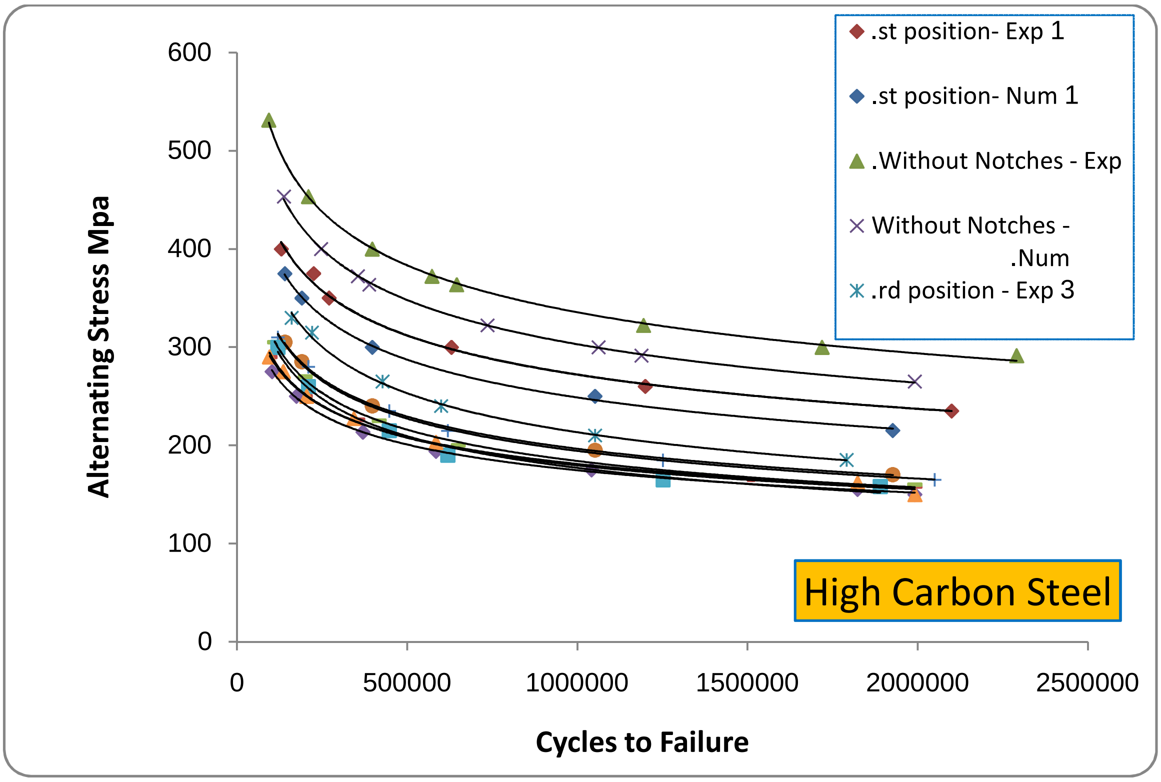

Figure 7: Numerical and Experimental S-N Curves for V Notched Specimens Made of High Carbon Steel with Different Positions

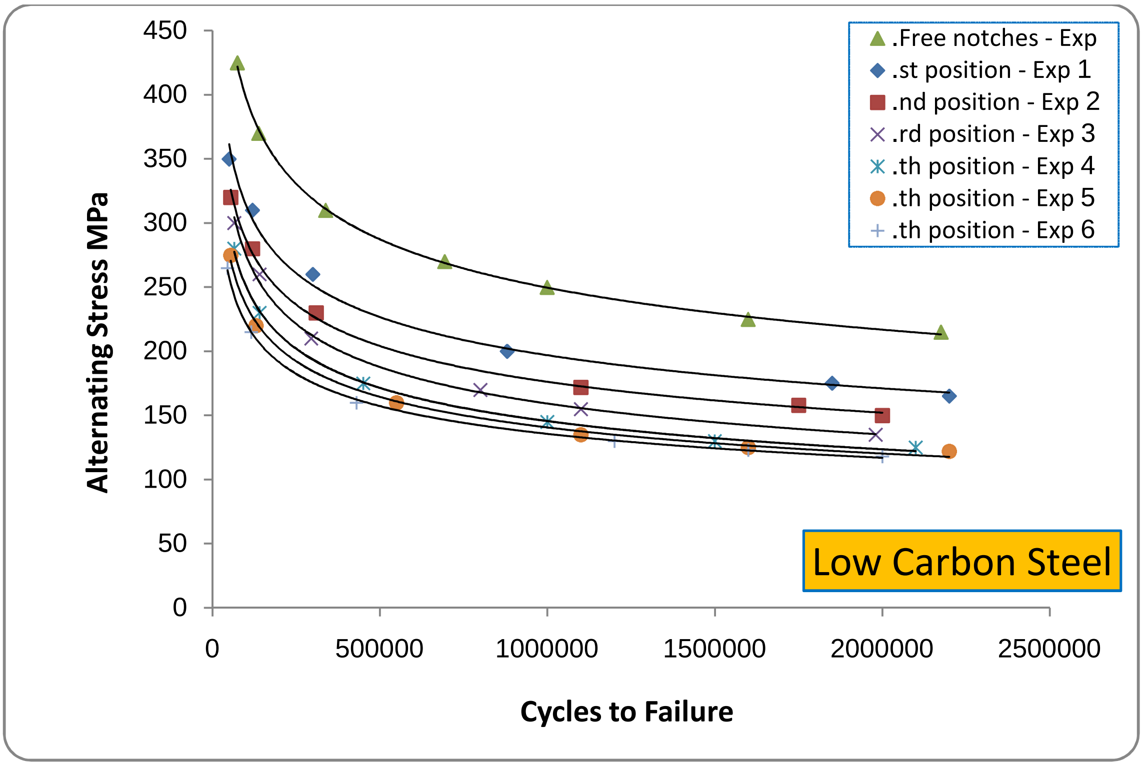

Figure 8: Experimental S-N Curves for V Notched Specimens Made of Low Carbon Steel with Different Positions

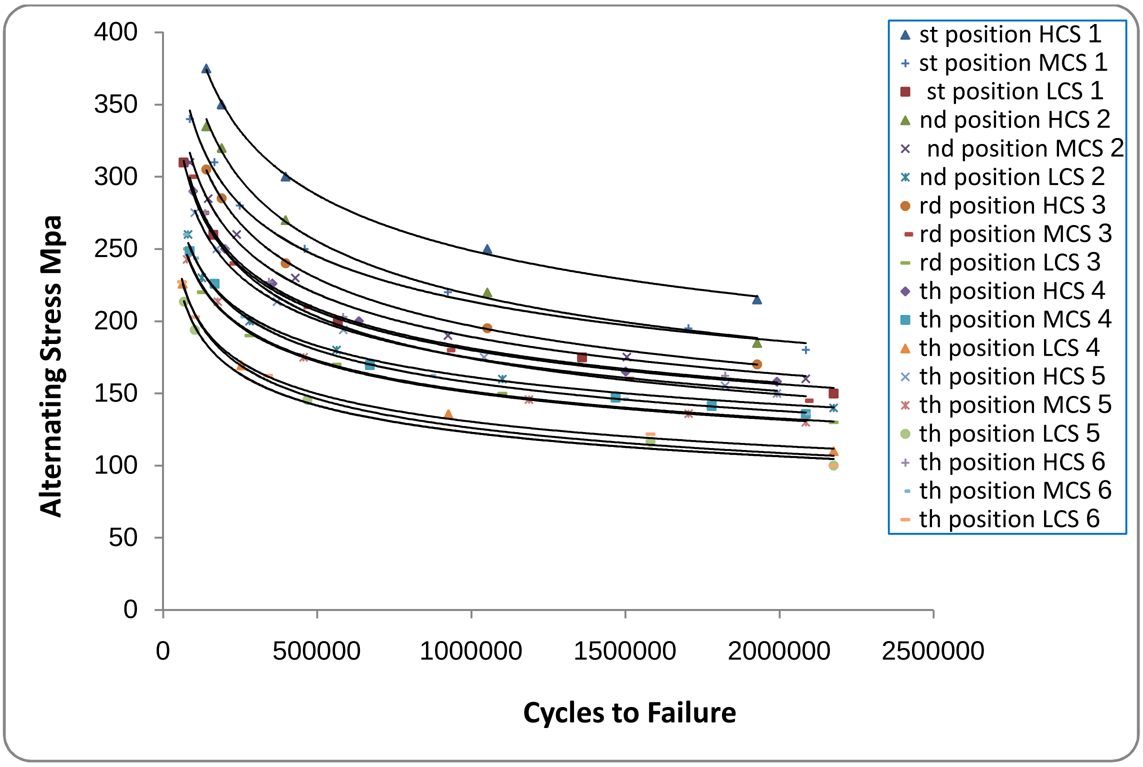

Figure 9: Numerical and Experimental S-N Curves for V Notched Specimens Made of Carbon Steel Alloys with Different Content of Carbon with Different Positions

CONCLUSIONS

The problem of determining the most severe notch position and opening angle ((i.e. the angle providing the cylindrical shafts under reversed bending for different content of carbon in alloy of steels been addressedin the present paper. Under the assumptions of notch sharpness, it was found that, according to the stress life approach that the notch position became no any influence on fatigue data when the distance from the maximum portion equals to 0.5 of the gauge length total regardless the type of alloy used.The results depends both onnotch depth and material properties.The accuracy of prediction in this method depends on of HCF data of cylindrical specimens and the accuracy of simulated value of maximum stress of notched specimens. Numerical finding is in agreement with most of the experimental data available in the literature with maximum error between two methods found 13 %.The final conclusion can be made from the results obtained that the S-N Curve generated from fatigue test of round specimen can also be used for the prediction of life for notched specimens based on actual stress developed at notch tip. From the results it is also observed that in most of the cases the predicted life is found to be less compared to experimental values for all the types of notched specimens. This may be due to the fact that the life has been predicted based on maximum stress in notched section [15]. The maximum value of stress occurs at the vicinity of change in cross section of the specimen where a relief groove is present. It is observed that the life prediction FE simulation is acceptable for different stress amplitudes and also at different no of cycles. The common stress life curve generated from specimens of several notch angles gives a better prediction, which is apparent from the figure 5,6,7,8&9.

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